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Electron beam dynamics of SAMEER linac

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Abstract : In the design of a linac such as the 4 MeV linac fabricated at SAMEER, simulation of electron beam dynamics plays an important role. We study electron beam dynamics to help in design of buncher cavity dimensions, linac length and effect of beam loading on electron energy and spectrum. We have written a program to calculate the electron trajectories for a given power input, with cavity dimensions, rf couplings and electron beam input voltage and current as parameters. By calculating the trajectories of electrons arriving at different rf phases, we get the average electron energy, percent of beam transmitted and electron energy spectrum. By running the program with different input parameters, we can choose the best combination for a required application such as radiography or cancer therapy.

Keywords : Electron beam dynamics, bunching, energy spectrum.

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1. Introduction

In the linear accelerator (linac), the electron beam passes through a chain of resonant cavities to gain energy from the rf field. A schematic figure of the electron linac is shown in Figure 1. The resonant cavities are excited in TM_{010} mode. The 4 MeV standing wave coupled cavity type linac made in SAMEER operates in the $\pi/2$ mode. The length of each cavity is such that the electron crosses the cavity in half cycle of rf oscillation. Thus the electron in its transit through the cavities always sees an accelerating electric field.

The first two cavities in the linac are the buncher cavities. The main function of the buncher cavities is to trap maximum number of electrons which are emitted from the electron gun and to form close bunches. For a given buncher configuration there is a definite phase interval of the rf cycle in which the injected electrons are trapped and these bunches are accelerated in the remaining cavities. It is necessary to optimise the electric field in the buncher and the length of the buncher cavity for best bunching. We report on the computer aided design of various linac parameters for best operation of linacs, given the input parameters and for required output values.

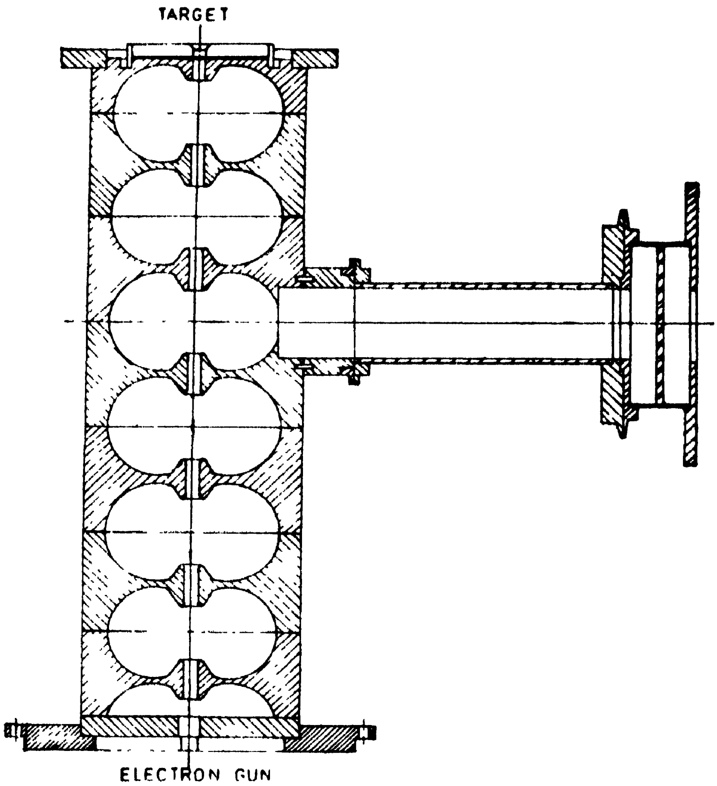

Figure 1. Schematic figure of electron linac.

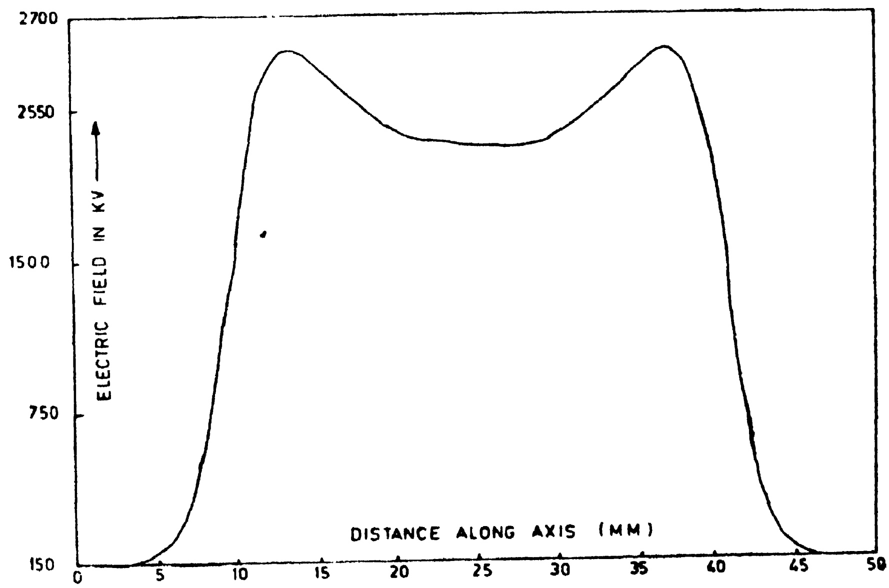

Figure 2. Electric field variation along linac axis.

2. Beam dynamics program

2.1. *Input parameters :*

The input parameters for the computer program are as follows

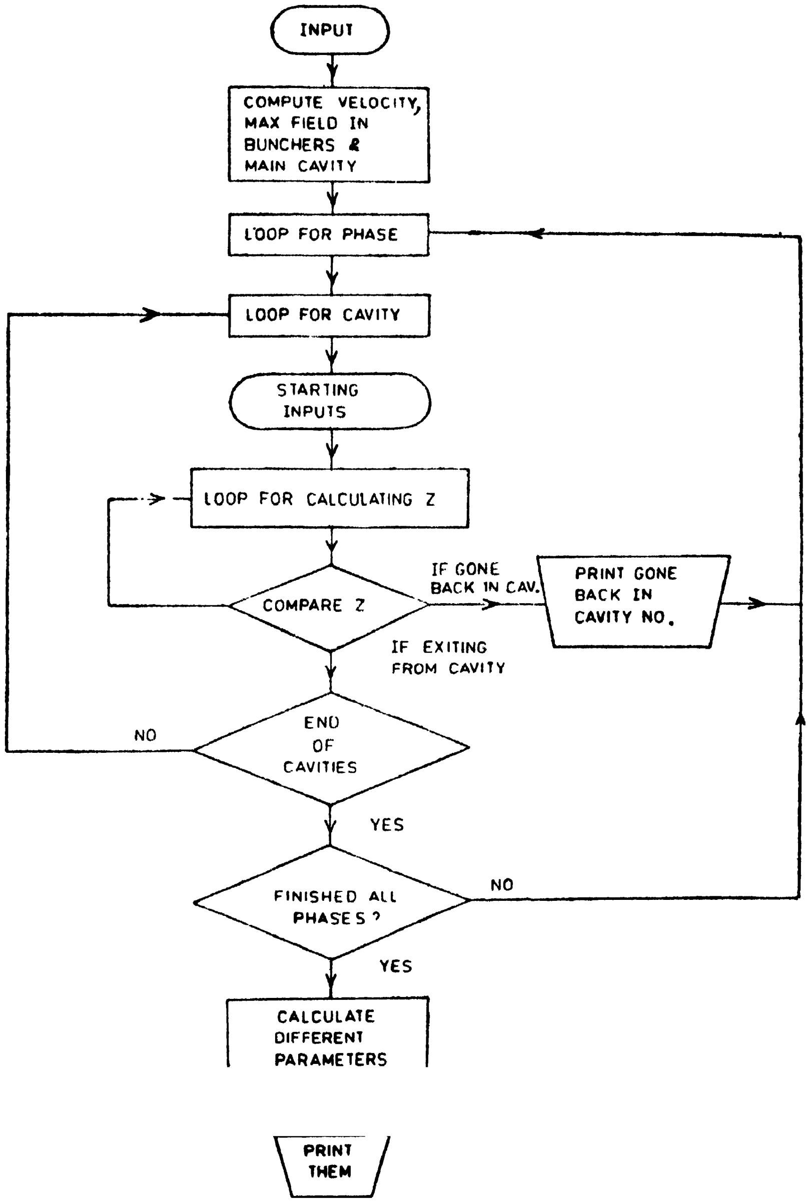

Figure 3. Block diagram of beam dynamics program.

Number of cavities, target current, injection voltage, rf power input, rf pulse period and Q of linac.

2.2. *Method of calculation :*

The cavity shape and its dimensions have been designed by using a different program MULA (Bhide and Shanker 1988). The basic equation used in the beam dynamics calculation is Newton's Law of Motion for relativistic particles :

$$\frac{d}{dt}(mv) = eE(z,t) \tag{2.1}$$

where

$E(z, t)$ is the rf field and

$m = \gamma m_0$, where $\gamma = \sqrt{1-(v^2/c^2)}$

The initial value of mv is calculated from the injection voltage. In Figure 2 the calculated electric field variation along the axis of the linac is shown (Bhide and Shanker 1988). The Mathematical expression for the field is approximated by a combination of straight lines and a parabola. The input Rf power was used to calculate the field values along the axis, using the shunt impedence calculation from MULA program and the equivalent circuit of the linac (Sitaram *et al* 1983). The sequence of operation of the program is given in Figure 3.

Table I. Variation of trapping efficiency with injection voltages.

Sr. No.	V_{inj} kV	Trapping angle	Trapping efficiency %
1	8	−157 to −16	38.6
2	10	·162 to −13	40.8
3	12	−166 to −11	42 5
4	16	· 173 to −7	45.5
5	20	−178 to −4	47.7

3. Results and conclusions

The input parameters can be varied suitably to obtain desired outputs. The program gives the following outputs : Trapping efficiency, bunching, average energy and energy spectrum.

3.1. *Trapping efficiency :*

The trapping angles mainly depend upon the injection voltage, buncher configuration and buncher field. The variation of trapping efficiency for different injection voltages is shown in Table 1.

Trapping efficiency increases with injection voltage. The limit on the injection voltage is due to breakdown phenomenon occurring in electron gun region.

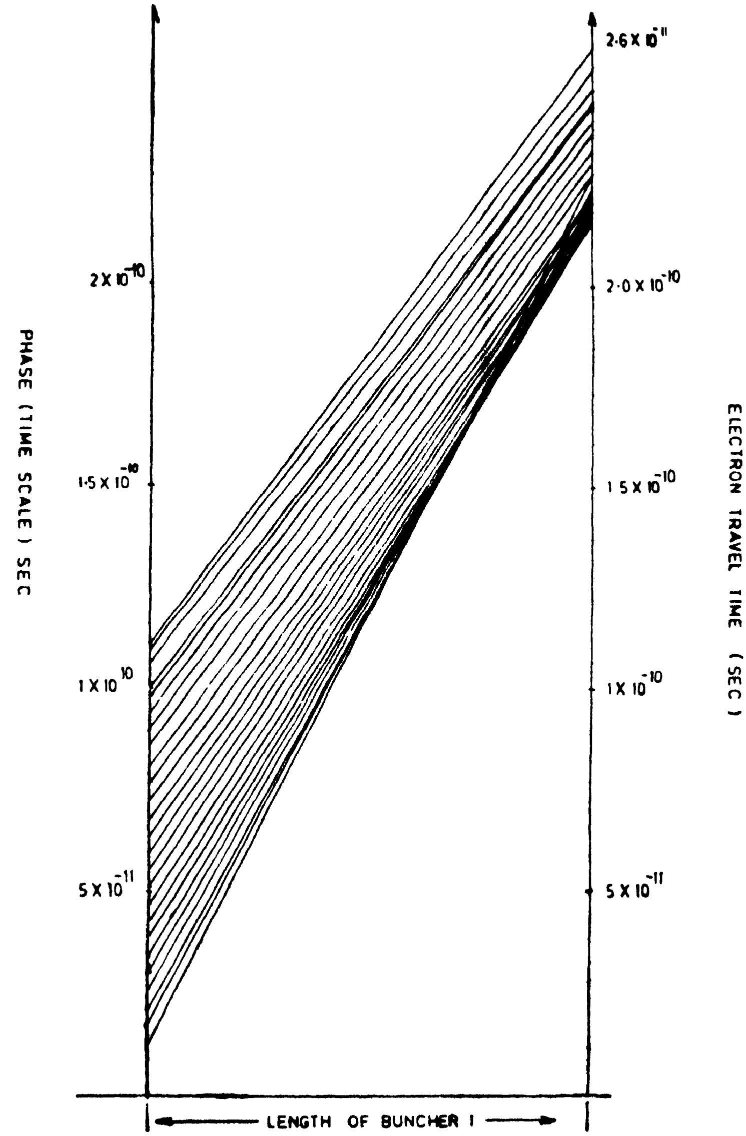

Figure 4. Electron bunching process.

3.2. Bunching :

This program was used to study the process of bunching in the buncher cavities of the linac. The result for the first bunching cavity is shown in Figure 4. This illustrates that the spread between the electrons after first buncher is only one-third of the spread before entering the buncher cavity. Efficient bunching of electron does take place in the first buncher cavity. Similar calculations for second buncher cavity shows that this cavity also contributes to the bunching process.

Table 2. Variation of average energy with target current.

Sr. No.	C_{in}, mA	Average energy MeV
1	38	4.912
2	50	4.761
3	85	4.338

3.3. *Average energy :*

The variation of the average energy with target current is given in Table 2. As the target current increases the average energy decreases.

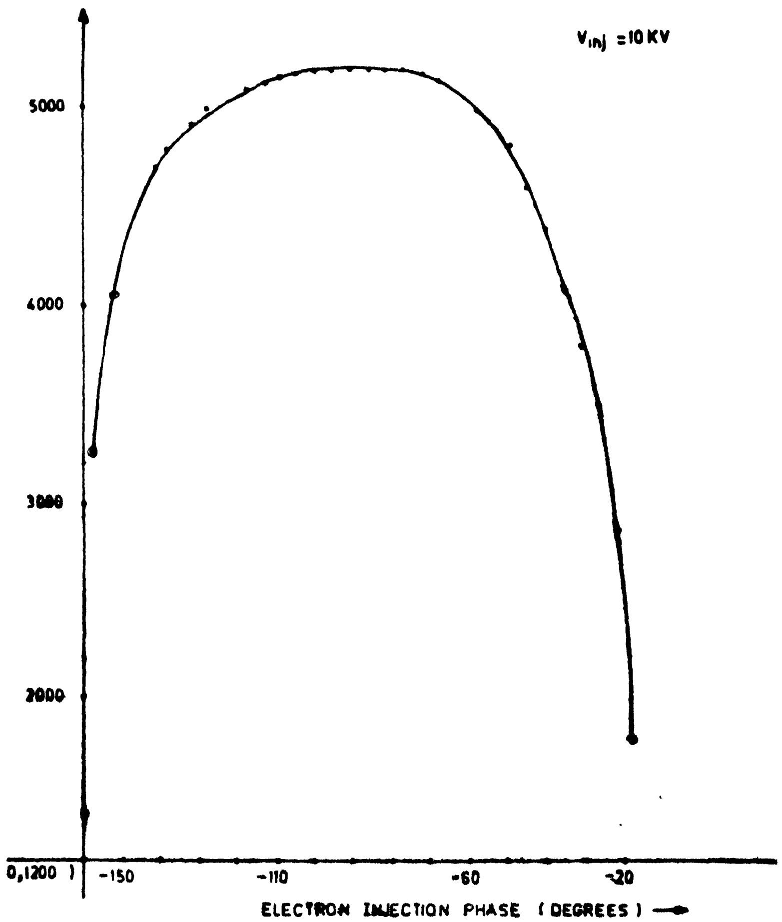

Figure 5. Energy spectrum.

3.4. Energy spectrum :

The energy spectrum for the different phase angles was also observed. The variation of electron energy with phase angles of the rf wave is shown in Figure 5.

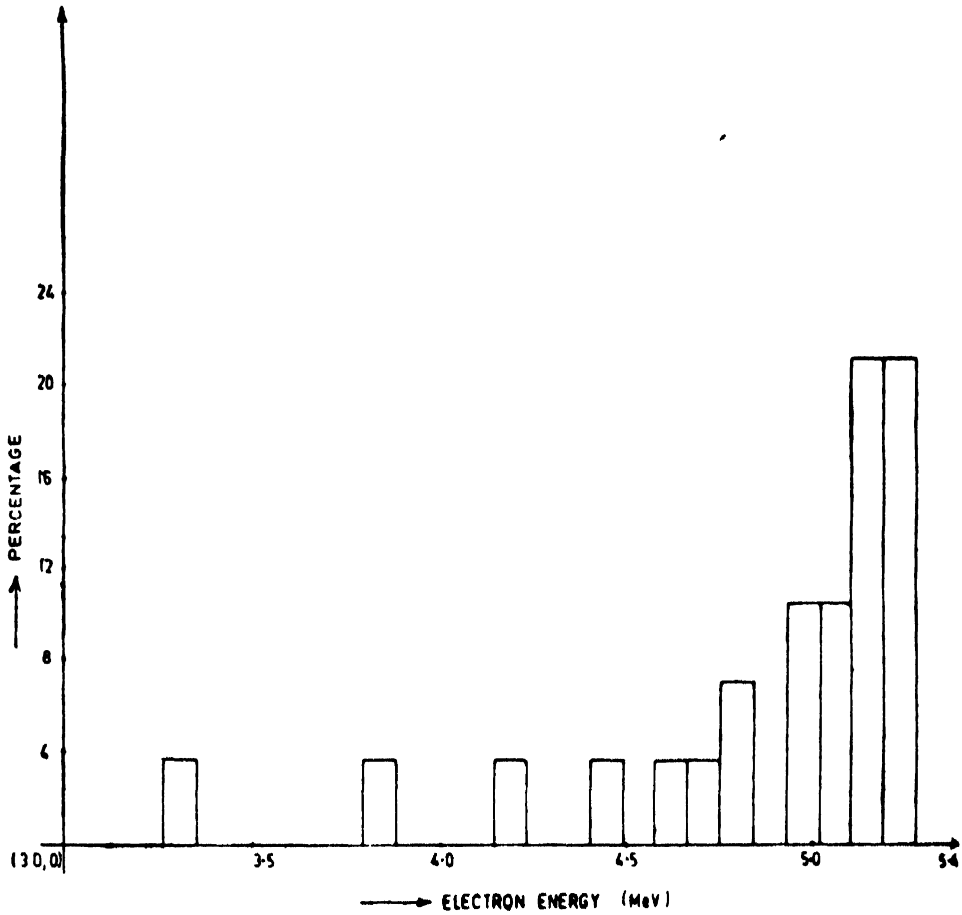

Figure 6. Histrogram.

A histogram is as shown in Figure 6. The histogram shows that the energy values are concentrated within a small range which indicates that bunching action is effective.

References

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